GOVERNMENT POLYTECHNIC, SIRSA (HARYANA)

ELECTRICAL ENGINEERING DEPARTMENT

SUBJECT – ELECTRICAL MACHINE-II

SEMESTER- 5TH

CHAPTER-1

3-PHASE INDUCTION MOTORS

The three-phase induction motors are the most widely used electric motors in industry. Induction machines are also called **asynchronous machines** i.e., the machines which never run at a synchronous speed.

Three phase induction motors are the most commonly used AC motors in the industry because;

1. They have simple and rugged construction
2. Low cost
3. High efficiency
4. Reasonably good power factor
5. Self-starting and
6. Low maintenance cost.

Almost more than 90% of the mechanical power used in industry is provided by three phase induction motors.

They run at essentially **constant speed** from **no-load to full-load**. However, the speed is frequency dependent and consequently these motors are not easily adapted to speed control.

Construction of 3-Phase Induction Motor:

A 3-phase induction motor has two main parts:

1. Stator
2. Rotor

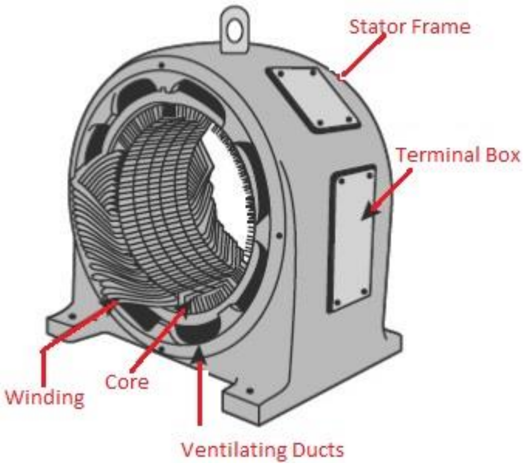
(1) Stator: It is the stationary part of the motor. It has three main parts:

(i) Outer frame,
(ii) Stator core
(iii) Stator winding.

Outer frame:

- It is the outer body of the motor.
- Its function is to support the stator core and to protect the inner parts of the machine.
- **In small machines** the fame is made of cast iron.
- **In large machines** the frame is made of fabricated steel.

To install the motor on the foundation, feet are provided in the outer frame.



Stator core*:*

When AC supply is given to the induction motor, an alternating flux is set -up in the stator core.

This alternating field produces hysteresis and eddy current loss.

To minimise these losses, the core is made of high grade silicon steel stampings.

Stator winding:

The stator core carries a three phase winding which is usually supplied from a three phase supply system.

The six terminals of the winding (two of each phase) are connected in the terminal box of the machine.

(2) Rotor: The rotating part of the motor is called *rotor.*

Two types of rotors are used for 3-phase induction motors.

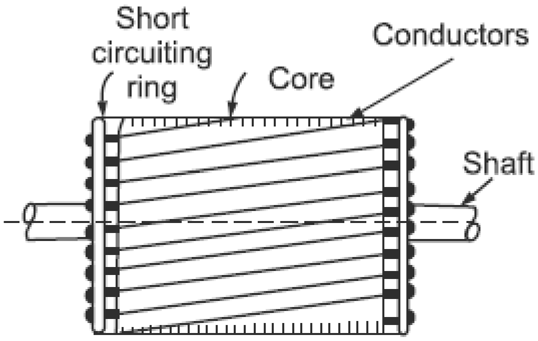
(i) Squirrel cage rotor
(ii) Phase wound rotor.

Squirrel cage rotor:

The motors in which these rotors are employed are called **Squirrel cage induction motors.**

A squirrel cage rotor consists of a laminated cylindrical core having semi-closed circular slots at the outer periphery.

Copper or aluminium bar conductors are placed in these slots and short circuited at each end by copper or aluminium rings, called short circuiting rings (as shown in Fig)



Thus, in these rotors, the rotor winding is permanently short-circuited and no external resistance can be added in the rotor circuit.

The slots are not parallel to the shaft but these are **skewed**.

The skewing provides the following advantages:

1. It reduce the humming noise and ensures quiet running.
2. Smooth and sufficient torque is obtained.
3. It reduces the magnetic locking of the stator and rotor,
4. It increases the rotor resistance due to the increased length of the rotor bar conductors.

Slip Ring or Phase wound rotor*:*

It is also known as slip ring rotor.

The motors in which these rotors are employed are known as **Phase wound** or **slip ring induction motors.**

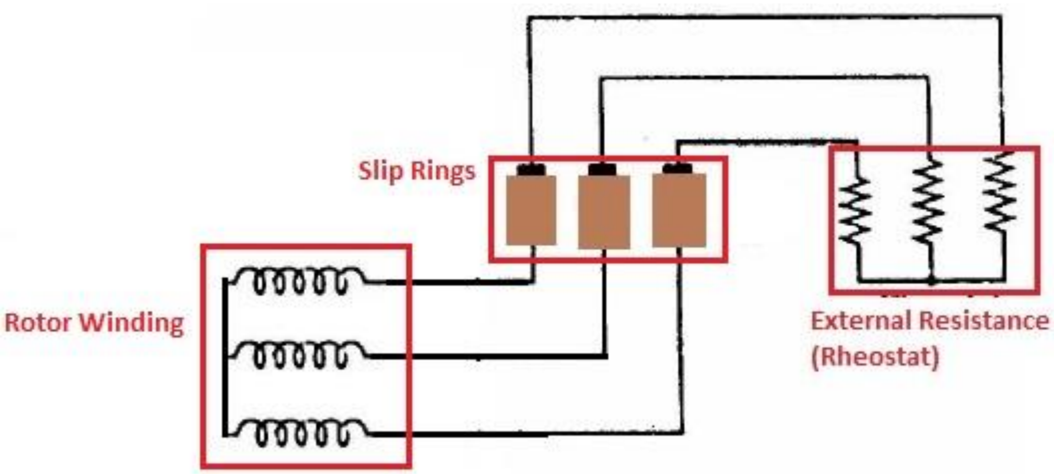
This rotor is also cylindrical in shape which consists of large number of stampings. A number of semi-closed slots are punched at its outer periphery.

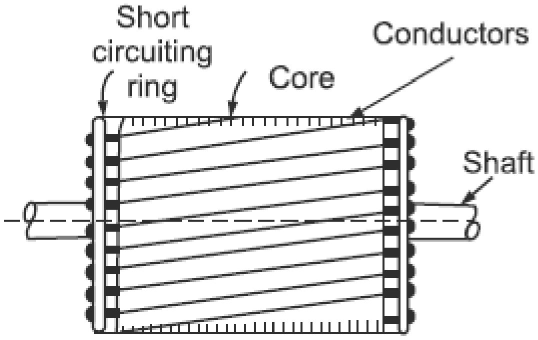
A 3-phase insulated winding is placed in these slots. The rotor is wound for the same number of poles as that of stator.

The rotor winding is connected in star and its remaining three terminals are connected to the slip rings. The three brushes are connected to a 3-phase star-connected Rheostat.

In this case, depending upon the requirement any external resistance can be added in the rotor circuit. In this case also the rotor is skewed.

At starting, the external resistances are included in the rotor circuit to give a large starting torque. These resistances are gradually reduced to zero as the motor runs up to speed. The external resistances are used during starting period only. When the motor attains normal speed, the three brushes are short-circuited so that the wound rotor runs like a squirrel cage rotor.





SLIP:

In an induction motor, the speed of rotor is always less than synchronous speed.
The difference between the speed of revolving field (Ns) and the rotor speed (N) is called **slip**.
It is represented by symbol **S**.
It is usually expressed as a percentage of synchronous speed i.e.,

$$\% \text{ age slip, } s = \frac{N_s - N}{N_s} \times 100$$

The difference between synchronous speed and rotor speed is called *slip speed* i.e.,

Slip speed = Ns – N

The value of slip at full load varies from about 6% small motors to about 2% for large motors.

(i) The quantity Ns ⍰⍰N is sometimes called **slip speed**.
(ii) When the rotor is stationary (i.e., N = 0), slip, s = 1 or 100 %.

(iii) In an induction motor, the change in slip from no-load to full-load is hardly 0.1% to 3% so that it is essentially a constant-speed motor.

IMPORTANCE OF SLIP:

Slip plays an important role in the operation of an induction motor. We have already seen that the difference between the rotor speed and synchronous speed of flux determine the rate at which the flux is cut by rotor conductors and hence the magnitude of induced emf i.e., $\mathbf{e_2 \alpha N_s - N}$

And $\mathbf{T \alpha S}$

Thus, greater the slip greater will be the induced emf or rotor current and hence larger will be the torque developed.

<u>At no-load</u>: The induction motor requires small torque to meet with the losses only such as mechanical, iron and other losses. Therefore rotor speed at no-load is very high and the slip is very small.

<u>At load:</u> Greater torque is required to drive the load, therefore, the slip increases and rotor speed decreases slightly.

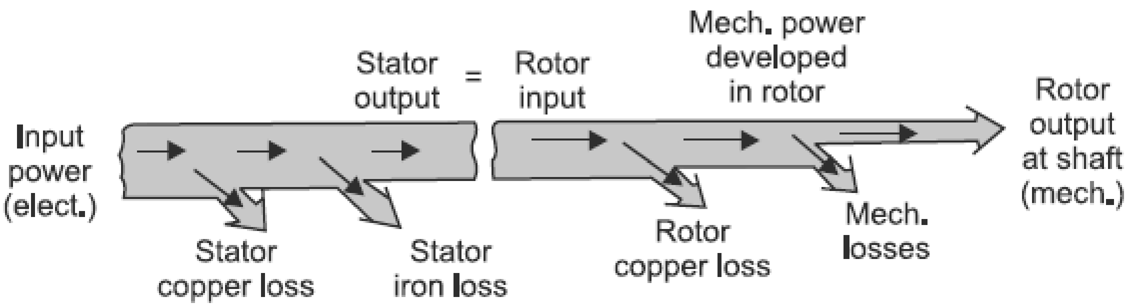
Thus, it is seen that ship in an induction motor adjusts itself to such a value so as to meet the required driving torque under normal operation.

POWER FLOW DIAGRAM:

Electrical power input is given to the stator. There are stator copper and iron losses and the remaining power i.e., stator output is transferred to the rotor through magnetic flux called **rotor input**.

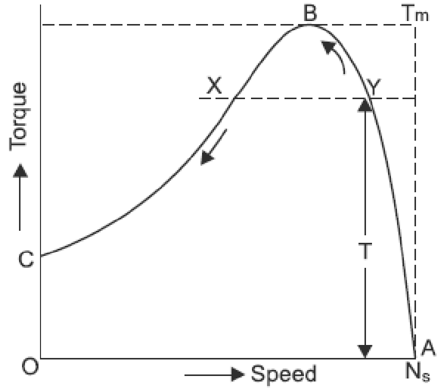
In the rotor there are rotor copper losses and the remaining power is converted into mechanical power called **mechanical power** developed in the rotor. Then there are mechanical losses and the remaining power is available at the shaft called **mechanical power output.**

The power flow diagram



TORQUE-SLIP CURVE AND OPERATING REGION:

The torque-speed curve of an induction motor is shown in Fig.



From the curve, it is clear that induction motor develops the same torque at point *X* and *Y*. However at point *X* the motor is unstable because with the increase in load speed decreases and the torque developed by the motor also decreases. Therefore, the motor could not pick up the load and the result is that the motor slows down and eventually stops. The miniature circuit breakers will be tripped open if the circuit has been so protected.

At point *Y*, the motor is stable because in this region with the increase in load speed decreases but the torque developed by the motor increases. Thus the motor will be in position to pick up the extra load effectively.

Thus, on the torque-speed curve region BC is the unstable region and **region AB is the stable or operating region** of the induction motor as shown in above fig.

LOSSES IN INDUCTION MOTOR:

Various losses which occur in an induction motor during energy conversions are given below:

1. Constant losses
2. Variable losses.

Constant losses: The losses which are independent of the load and remain constant irrespective of the load variation are called constant losses. These losses may be:

(i) Core losses: These include hysteresis and eddy current losses in stator as well as in rotor core.

(ii) Friction and wind-age losses: These losses are also constant as these losses depend upon the speed of the induction motor.

Variable losses: The losses which depend on the load and change with the variation in load are called variable losses. These losses are:

(*a*) I^2R loss in stator winding.

(*b*) $I^2 R$ loss in rotor winding.

These losses occur due to the resistance of stator winding as well as resistance of rotor winding. This loss is also called **copper loss**.

It is proportional to the square of the current following in the stator as well as in rotor winding.

(*c*) **Brush contact loss:** This loss occurs only in slip ring induction motors. This is occurring because of contact resistance between brushes and slip rings. Its magnitude is very small.

Stray losses: These losses are occurring in iron as well winding of the machine. These cannot be determined exactly but are accounted for when the efficiency of the machine is calculated, by suitable factor.

SLIP-RING MOTORS VERSUS SQUIRREL CAGE MOTORS:

The slip-ring induction motors have the following **advantages** over the squirrel cage motors:

(i) High starting torque with low starting current.
(ii) Smooth acceleration under heavy loads.
(iii) No abnormal heating during starting.
(iv) it has good running characteristics after external rotor resistances are cut out.
(v) Adjustable speed.

The **disadvantages** of slip-ring motors are:

(i) The initial and maintenance costs are greater than those of squirrel cage motors.
(ii) The speed regulation is poor when run with resistance in the rotor circuit

COGGING IN INDUCTION MOTOR:

The phenomenon of **Magnetic Locking** between the stator and the rotor teeth is called **Cogging** or **Teeth Locking**. Even after applying full voltage to the stator winding, the rotor of a 3 phase induction motor fails to start. This condition arises when the number of stator and rotor slots are either equal or have an integral ratio.

CRAWLING IN THREE-PHASE INDUCTION MOTORS:

In a three-phase induction motor, the fundamental frequency produces the synchronous torque due to which rotor starts rotating at its rated speed. However, in the induction motors, harmonics are developed out of which 5th and 7th harmonics are more important. These harmonics generate rotor emfs, currents and torques of the same general torque/speed shape as that of the fundamental but with synchronous speeds 1/5th (backward) and 1/7th (forward) of the fundamental synchronous speed.

APPLICATIONS OF INDUCTION MOTOR:

The applications of squirrel cage induction motors and slip-ring (phase wound) induction motors are given below:

1. SQUIRREL CAGE INDUCTION MOTORS: These motors are mechanically robust and are operated almost at constant speed. These motors operate at high power factor and have high over load capacity. However, these motors have low starting torque. (i.e., these motors cannot pick-up heavy loads) and draw heavy current at start. On the bases of these characteristics, these motors are best suited for:

- (a) Printing machinery
- (b) Flour mills
- (c) Saw mills
- (d) Shaft drives of small industries
- (e) Pumps
- (f) Prime-movers with small generators etc.

2. SLIP-RING (OR PHASE-WOUND) INDUCTION MOTORS: These motors have all the important characteristics (advantage) of squirrel cage induction motors and at the same time have the ability to pick-up heavy loads at start drawing smaller current from the mains. Accordingly these motors are best suited for;

(a) Rolling mills
(b) Lifts and hoists
(c) Big flour mills
(d) Large pumps
(e) Line shafts of heavy industries
(f) Prime-moves with medium and large generators

CHAPTER-2

SINGLE PHASE INDUCTION MOTORS

These motors, usually have output less than one horse-power or one kilowatt, hence are called *fractional horse-power* or *fractional kilowatt motors.* AC single-phase, fractional kilowatt motors perform variety of services in the homes, offices, business concerns, factories etc. Almost in all the domestic appliances such as refrigerators, fans, washing machines, hair driers, mixer grinders etc., only 1-phase induction motors are employed.

TYPES OF SINGLE-PHASE MOTORS

Single-phase motors are generally built in the fractional-horsepower range and may be classified into the following four basic types:

1. SINGLE-PHASE INDUCTION MOTORS

(i) split-phase type

(ii) capacitor type

(iii) shaded-pole type

2. A.C. SERIES MOTOR OR UNIVERSAL MOTOR

3. REPULSION MOTORS

(i) Repulsion-start induction-run motor

(ii) Repulsion-induction motor

4. SYNCHRONOUS MOTORS

(i) Reluctance motor (ii) Hysteresis motor

NATURE OF FIELD PRODUCED IN SINGLE PHASE INDUCTION MOTOR

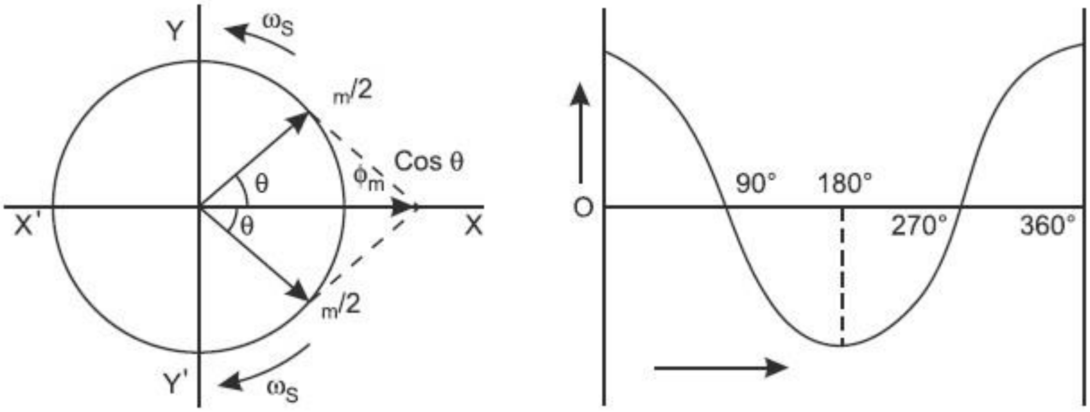
The field produced in a single-phase induction motor can be explained by double revolving field theory which is given below:

This theory is based on the **Ferraris Principle** that pulsating field produced in single phase motor can be resolved into two components of half the magnitude and rotating in opposite direction at the same synchronous speed.

Thus the alternating flux which passes across the air gap of single phase induction motor at stand still consists of combination of two fields of same strength which are revolving with same speed, one in clockwise direction and the other in anticlockwise direction. The strength of each one of these fields will be equal to one half of the maximum field strength of the actual alternating field as shown in Fig. (a).

Let ϕ_m be the pulsating field which has two components each of magnitude $\phi_m/2$. Both are rotating at the same angular speed ω_s rad/sec but in opposite direction as shown in Fig. (a).

The resultant of the two fields is $\phi_m \cos\theta$. This shows that resultant field varies according to cosine of the angle θ. The wave shape of the resultant field is shown in Fig.(*b*).



(a) Phasor Diagram

(b) Wave Diagram

Two Field Revolving Theory

METHODS TO MAKE SINGLE PHASE MOTOR SELF-STARTING:

A single-phase induction motor inherently is not self-starting. To make it self-starting, some method is required to be evolved to produce a revolving magnetic field in the stator core. Accordingly, depending upon the method used to make a 1-phase induction motor self-starting, single-phase induction motors can be classified as:

1. SPRIT-PHASE MOTORS: These motors are started by employing two-phase motor action through the use of an auxiliary winding called starting winding.

2. CAPACITOR MOTORS: These motors are started by employing two-phase motor action through the use of an auxiliary winding with capacitor.

3. SHADED-POLE MOTORS: These motors are started by the interaction of the field produced by a shading band or short circuiting ring placed around a portion of the pole structure.

SPLIT PHASE MOTOR

CONSTRUCTION:

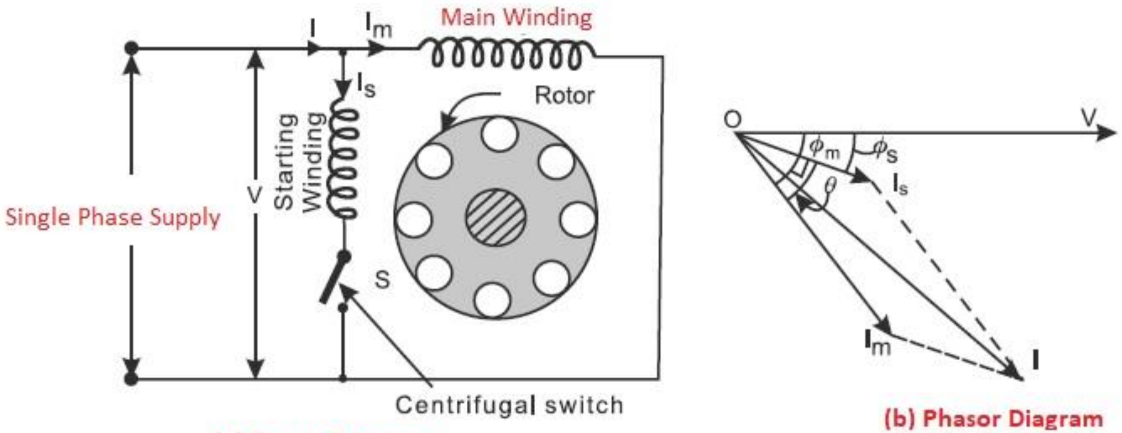
The outer frame and stator core of a split-phase motor is similar to the outer frame and stator core of a 3-phase induction motor.

It is provided with an **auxiliary stator winding** called **starting winding** in addition to main winding. These windings are placed in the stator slots. Both the windings are put in parallel as shown in Fig.(*a*).

The purpose is to get two different currents sufficiently displaced from each other so that a revolving field is produced. The main winding which is highly inductive is connected across the line in the usual manner. The auxiliary or starting winding has a greater resistances and lesser reactance as compared to main winding.

The current in the starting winding I_s lags the supply voltage by lesser angle ϕ_s whereas the current in the main winding I_m being highly inductive lags the supply voltage by greater angle ϕ_m as shown in Fig.(b). The two currents have a phase difference of θ° electrical. Thus, a revolving field is set-up in the stator and a starting torque is developed in the rotor.

Consequently rotor starts rotating and picks up the speed. A centrifugal switch which is normally closed is incorporated in series with the starting winding. When the motor attains a speed about 75% of synchronous speed, the centrifugal switch is opened automatically with the help of centrifugal force and puts the starting winding out of circuit. It is important that the centrifugal switch should open otherwise the auxiliary winding being made of thin wire will be over heated and may damage.



(a) Circuit Diagram

(b) Phasor Diagram

FIG: SPLIT PHASE INDUCTION MOTOR

APPLICATIONS:

As starting torque is not so high so this machine is not used where large starting torque is required. It is used in

(1) Washing machines
(2) Fans
(3) Blowers
(4) Wood working tools
(5) Grinders

CAPACITOR MOTOR:

It is also a split phase motor.

In this motor, a capacitor is connected in **series with the starting winding**.

In these motors, the angular displacement between I_S and I_m can be made nearly 90°and high starting torques can be obtained since starting torque is directly proportional to sine of angle θ.

The capacitor in the starting winding may be connected permanently or temporarily. Accordingly, capacitor motors may be

1. Capacitor start motors.
2. Capacitor run motors.
3. Capacitor start and capacitor run motors.

CAPACITOR START MOTORS:

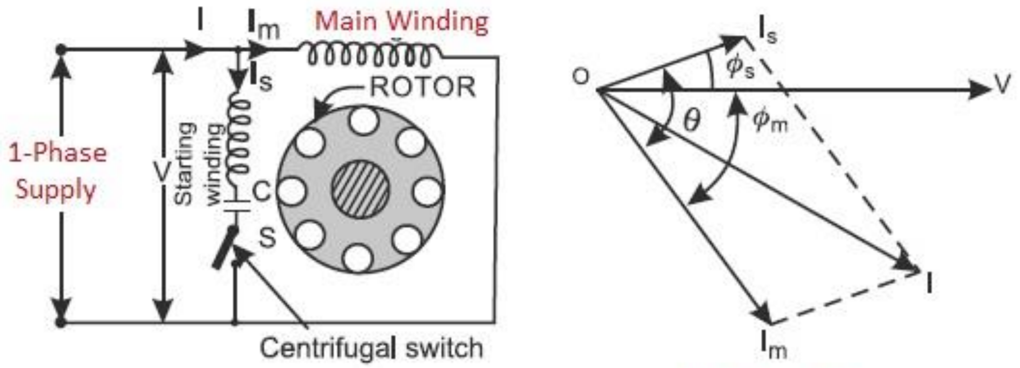
In the capacitor start induction motor capacitor **C** is of large value such that the motor will give high starting torque since torque T x sin θ and in this case, the phase angle between **I_m** and **I_S** is made near to 90°, as shown in Fig. (b).

Capacitor employed is of short time duty rating.

Capacitor is of electrolytic type.

Electrolytic capacitor **C** is connected in series with the starting winding along with centrifugal switch **S** as shown in Fig. (*a*).

When the motor attains the speed of about 75% of synchronous speed starting winding is cut-off.



(a) Ciruit Diagram

(b) Phasor Diagram

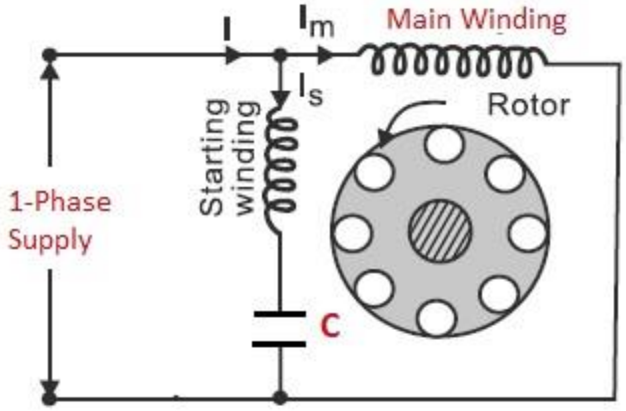
FIG: CAPACITOR START MOTOR

CAPACITOR RUN MOTORS:

In these motors, a paper capacitor is permanently connected in the starting winding, as shown in Fig.(*a*).

In this case, electrolytic capacitor cannot be used since this type of capacitor is designed only for short time rating and hence cannot be permanently connected in the winding.

Both main as well as starting winding is of equal rating.



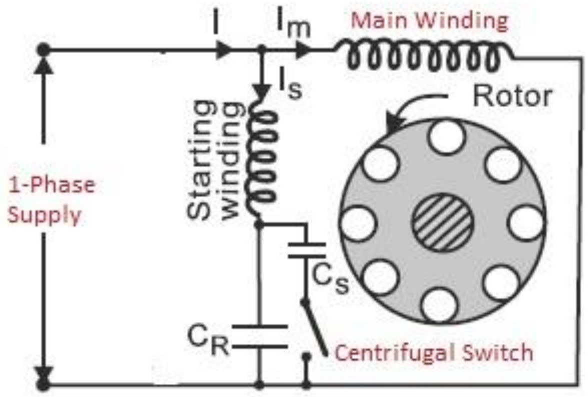
(a) Circuit Diagram

CAPACITOR START AND CAPACITOR RUN MOTORS:

In this case, **two capacitors** are used one for starting purpose and other for running purpose as shown in Fig. (*a*).

For starting purpose **an electrolytic type capacitor** (C_S) is used which is disconnected from the supply when the motor attains 75% of synchronous speed with the help of centrifugal switch *S*. Whereas, a **paper capacitor** (C_R) is used for running purpose which remains in the circuit of starting winding during running conditions.

Starting capacitor C_S which is of higher value than the value of running capacitor C_R.



(a) Circuit Diagram

SHADED POLE MOTOR:

CONSTRUCTION

Shaded pole motor is constructed with salient poles in stator.

Each pole has its own exciting winding as shown in Fig. (a).

A 1/3rd portion of each pole core is surrounded by a copper strip forming a closed loop called the **shading band** as shown in Fig (*a*). Rotor is usually squirrel cage type.

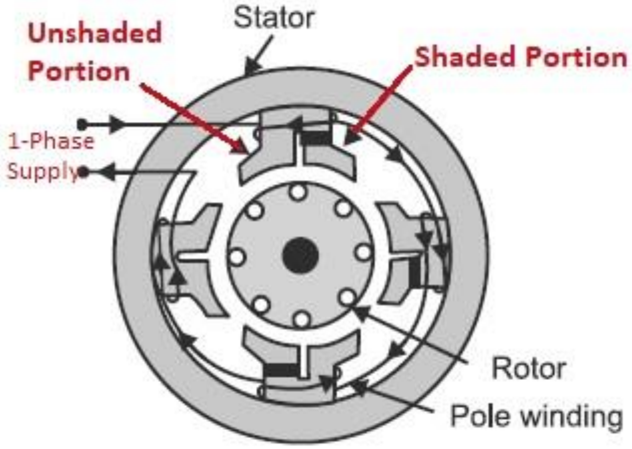


FIG. (a)- Shaded Pole Motor

When a single phase supply is given to the stator (exciting) winding, it produces alternating flux.

When the flux is increasing in the pole, a portion of the flux attempts to pass through the shaded portion of the pole. This flux induces an emf and hence current in the shading band or copper ring.

As per Lenz's law the direction of this current is such that it opposes the cause which produces it i.e., increase of flux in shaded portion.

Hence in the beginning, the greater portion of flux passes through unshaded side of each pole and resultant lies on unshaded side of the pole. When the flux reaches its maximum value, its rate of change is zero, thereby the emf and hence current in the shading coil becomes zero.

Flux is uniformly distributed over the pole face and the resultant field lies at the centre of the pole. After this the main flux tends to decrease, the emf and hence the current induced in the shading coil now tends to increase the flux on the shaded portion of the pole and resultant lies on the shaded portion of the pole as shown in above Fig.

Hence, a revolving field is set up which rotates from unshaded portion of the pole to the shaded portion of the pole as marked by the arrow head in Fig.

Thus, by electromagnetic induction, a starting torque develops in the rotor and the rotor starts rotating. After that its rotor picks up the speed.

HYSTERESIS MOTOR:

A hysteresis motor is a single-phase cylindrical (non-salient pole type) synchronous induction motor.

CONSTRUCTION

The stator construction of a hysteresis motor is either split-phase type or shaded-pole type which produces a revolving field in the stator when single phase AC supply is given to it.

The rotor of hysteresis motor is specially designed and is made of Hysteresis-type laminations of the shape shown in Fig. These are usually made of hardened high-retentivity steel rather than commercial low-retentivity dynamo steel. During operations, the cross arms of the rotor are permanently magnetised due to high-retentivity of the steel used for its construction.

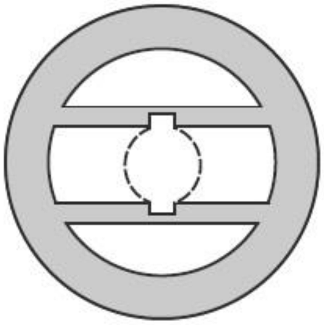


FIG: TWO POLE HYSTERESIS MOTOR

PRINCIPLE AND WORKING

When single-phase supply is given to the stator, a revolving magnetic field is set-up by it. Eddy currents are induced in the rotor. These eddy currents set up the rotor magnetic field which causes rotor to rotate.

A high starting torque is produced as a result of the high rotor resistance (proportional to the hysteresis loss). As the motor approaches synchronous speed, the frequency of current reversal in the cross bars decreases and the rotor becomes permanently magnetised in one direction through cross-arms as a result of high retentivity of the steel used for the construction of rotor. With the two permanently set field poles, the rotor will develop a speed of 3000 rpm at 50 Hz. Thus, the motor runs as a hysteresis motor on hysteresis torque because the rotor is permanently magnetised.

APPLICATIONS

The amount of torque produced as a result of rotor magnetisation is not as great as reluctance torque.

But hysteresis torque is extremely steady in both amplitude and phase in spite of fluctuations in supply voltage. As a result of this, these motors are extremely popular in

1. In high-quality cassette players
2. Compact disc (C.D) players
3. Record players
4. Tape recorders
5. Clocks

CHAPTER-3

SYNCHRONOUS MACHINE

Synchronous Motor Working Principle

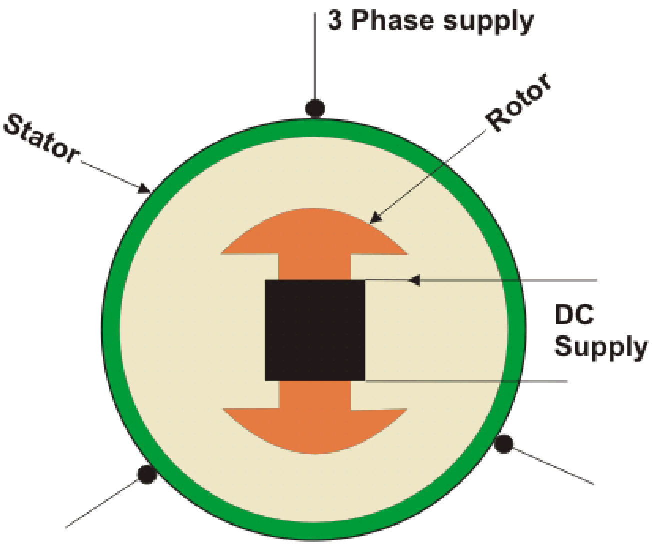
Electrical motor in general is an electro-mechanical device that converts energy from electrical domain to mechanical domain. Based on the type of input we have classified it into single phase and 3 phase motors. Among 3 phase motors, we mostly sue induction motors and **synchronous motors**. When three-phase electric conductors are placed in certain geometrical positions (In certain angle from one another), then an electrical field is generated. Now the rotating magnetic field rotates at a certain speed, that speed is called synchronous speed. Now if an electromagnet is present in this rotating magnetic field, the electromagnet is magnetically locked with this rotating magnetic field and rotates with the same speed of rotating field.

Synchronous motors is called so because the speed of the rotor of this motor is same as the rotating magnetic field. It is a fixed speed motor because it has only one speed, which is synchronous speed, or in other words, it is in synchronism with the supply frequency. Synchronous speed is given by

$$N_s = \frac{120f}{p}$$

Where, f = supply frequency and p = no. of poles

Construction of Synchronous Motor:



Synchronous Motor

Usually, its construction is almost similar to that of a 3 phase induction motor, except the fact that here we supply DC to the rotor. Now, let us first go through the basic construction of this type of motor. From the above picture, it is clear that how we design this type of machine. We apply three phase supply to the stator and DC supply to the rotor.

Main Features of Synchronous Motors:

1. Synchronous motors are inherently not self-starting. They require some external means to bring their speed close to synchronous speed to before they are synchronized.
2. The speed of operation of is in synchronism with the supply frequency and hence for constant supply frequency they behave as constant speed motor irrespective of load condition
3. This motor has the unique characteristics of operating under any electrical power factor. This makes it being used in electrical power factor improvement.
4. Synchronous motor will run either at synchronous speed or will not run at all.
5. The only way to change its speed is to change its supply frequency. (As Ns = 120f / P)

CONSTRUCTION OF A SYNCHRONOUS MACHINE

Alternator or motor consists of two main parts, namely the stator and the rotor. The stator is the stationary part of the machine. It carries the armature winding in which the voltage is generated. The output of the machine is taken from the stator. The rotor is the rotating part of the machine. The rotor produces the main field flux.

The important parts of the Synchronous Machine are given below.

- Stator
- Rotor
- Miscellaneous

STATOR CONSTRUCTION

The stationary part of the machine is called Stator. It includes various parts like stator frame, stator core, stator windings and cooling arrangement. They are explained below in detail.

(1) Stator Frame

It is the outer body of the machine made of cast iron, and it protects the inner parts of the machine.

(2) Stator Core

The stator core is made of silicon steel material. It is made from a number of stamps which are insulated from each other. Its function is to provide an easy path for the magnetic lines of force and accommodate the stator winding.

(3) Stator Winding

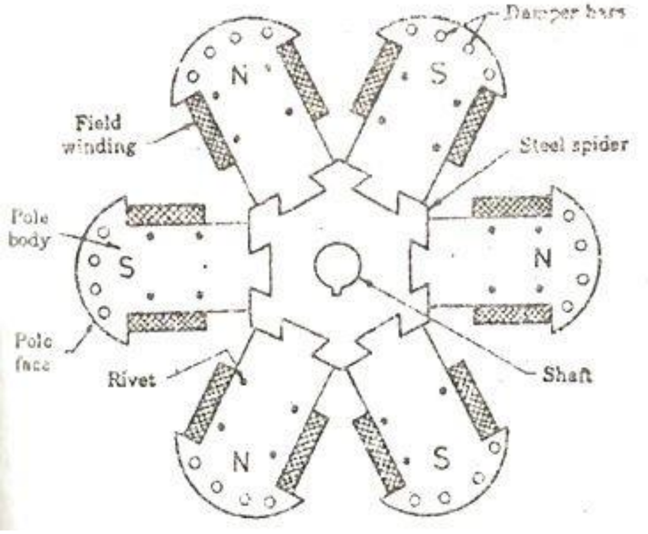
Slots are cut on the inner periphery of the stator core in which 3 phase or 1 phase winding is placed. Enameled copper is used as winding material. The winding is star connected. The winding of each phase is distributed over several slots. When the current flows in a distributed winding it produces an essentially sinusoidal space distribution of EMF.

ROTOR CONSTRUCTION

The rotating part of the machine is called Rotor. There are two types of rotor construction, namely the salient pole type and the cylindrical rotor type.

(1) SALIENT POLE ROTOR

The term salient means projecting. Thus, a salient pole rotor consists of poles projecting out from the surface of the rotor core. The end view of a typical 6 pole salient pole rotor is shown below in the figure.



Since the rotor is subjected to changing magnetic fields, it is made of steel laminations to reduce eddy current losses. Poles of identical dimensions are assembled by stacking laminations to the required length. A salient pole synchronous machine has a non uniform air gap. The air gap is minimized under the pole centers and it is maximum in between the poles.

They are constructed for the medium and low speeds as they have a large number of poles. A salient pole generator has a large diameter. The salient pole rotor has the following important parts.

(A) Spider

It is made of cast iron to provide an easy path for the magnetic flux. It is keyed to the shaft and at the outer surface, pole core and pole shoe are keyed to it.

(B) Pole Core and Pole Shoe

It is made of laminated sheet steel material. Pole core provides least reluctance path for the magnetic field and pole shoe distributes the field over the whole periphery uniformly to produce a sinusoidal wave.

(C) Field Winding or Exciting Winding

It is wound on the former and then placed around the pole core. DC supply is given to it through slip rings. When direct current flow through the field winding, it produces the required magnetic field.

(D) Damper Winding

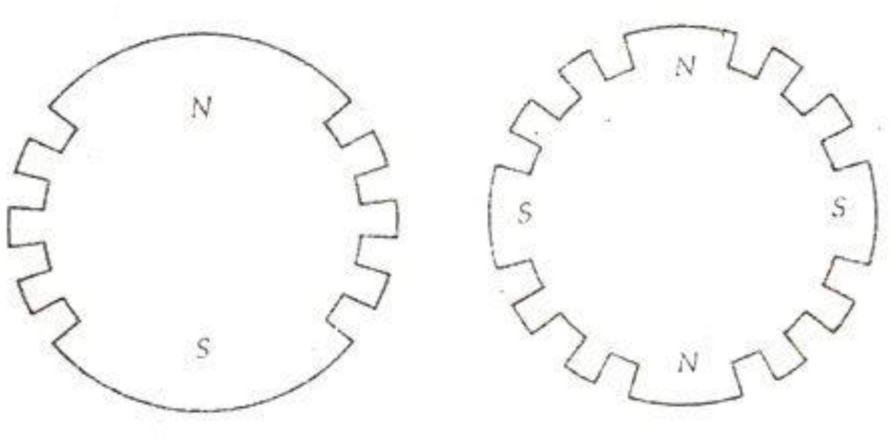
At the outermost periphery, holes are provided in which copper bars are inserted and short-circuited at both the sides by rings forming Damper winding.

(2) NON- SALIENT POLE ROTOR OR CYLINDRICAL ROTOR

In this type of rotor, there are no projected poles, but the poles are formed by the current flowing through the rotor exciting winding. Cylindrical rotors are made from solid forgings of high-grade nickel chrome molybdenum steel. It has a comparatively small diameter and long axial length.

They are useful in high-speed machines. The cylindrical rotor type alternator has two or four poles on the rotor. Such a construction provides a greater mechanical strength and permits more accurate dynamic balancing. The smooth rotor of the machine makes less windage losses and the operation is less noisy because of the uniform air gap.

The figure below shows the end view of the 2 pole and 4 pole cylindrical rotors.



They are driven by steam or gas turbines. Cylindrical synchronous rotor synchronous generators are called turbo alternators and turbo generators. The machines are built in a number of rating from 10 MVA to over 1500 MVA. The biggest size used in India has a rating of 500 MVA installed in the super thermal power plant.

Non-salient pole type rotors have the following parts. They are as follows

(A) Rotor Core

The rotor core is made of silicon steel stampings. It is placed on the shaft. At the outer periphery, slots are cut in which exciting coils are placed.

(B) Rotor Winding or Exciting Winding

It is placed on the rotor slots, and current is passed through the winding in such a way that the poles are formed according to the requirement.

(C) Slip Rings

Slip rings provide DC supply to the rotor windings.

(D) Miscellaneous Parts

The miscellaneous parts are given below.

(i) Brushes

Brushes are made of carbon, and they slip over the slip rings. A DC supply is given to the brushes. Current flows from the brushes to the slip rings and then to the exciting windings.

(ii) Bearings

Bearings are provided between the shaft and the outer stationary body to reduce the friction. They are made of high carbon steel.

(iii) Shaft

The shaft is made of mild steel. Mechanical power is taken or given to the machine through the shaft.

PRINCIPLE OF OPERATION SYNCHRONOUS MOTOR

Synchronous motor is a doubly excited machine, i.e. two electrical inputs are provided to it. Its stator winding which consists of a We provide three-phase supply to three-phase stator winding, and DC to the rotor winding. The 3 phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux. The rotor carrying DC supply also produces a constant flux. Considering 50 Hz power frequency, from the above relation we can see that the 3 phase rotating flux rotates about 3000 revolutions in 1 min or 50 revolutions in 1 sec. At a particular instant rotor and stator poles might be of the same polarity (N-N or S-S), causing a repulsive force on the rotor and the next instant it will be N-S causing attractive force. However, due to the inertia of the rotor, it is unable to rotate in any direction due to that attractive or repulsive force, and the rotor remains in standstill condition. Hence, a synchronous motor is not self-starting. Here we use some mechanical means that initially rotates the rotor in the same direction as the magnetic field to speed very close to synchronous speed. On achieving synchronous speed, magnetic locking occurs, and the synchronous motor continues to rotate even after removal of external mechanical means.

METHODS OF STARTING OF SYNCHRONOUS MOTOR

1. **Motor starting with an external prime Mover:** Synchronous motors are mechanically coupled with another motor. It could be either 3-phase induction motor or DC shunt motor. Here, we do not apply DC excitation initially. It rotates at speed very close to its synchronous speed, and then we give the DC excitation. After some time when magnetic locking takes place supply to the external motor is cut off.
2. **Damper winding**: In this case, the synchronous motor is of salient pole type, additional winding is placed in rotor pole face. Initially, when the rotor is not rotating, the relative

speed between damper winding and rotating air gap flux is large and an emf is induced in it, which produces the required starting torque. As speed approaches synchronous speed, emf and torque are reduced and finally when magnetic locking takes place; torque also reduces to zero. Hence in this case synchronous motor first runs as three phase induction motor using additional winding and finally it is synchronized with the frequency.

APPLICATION OF SYNCHRONOUS MOTOR

1. It is used for power factor improvement.
2. Reciprocating pump
3. Compressor
4. Rolling mills

DISTRIBUTION FACTOR:

The **Distribution Factor** or the **Breadth Factor** is defined as the ratio of the actual voltage obtained to the possible voltage if all the coils of a polar group were concentrated in a single slot. It is denoted by $\mathbf{K_d}$ and is given by the equation shown below.

$$K_d = \frac{\text{Phasor Sum of the coil volatges per phase}}{\text{Arithmetic sum of coil voltages per phase}}$$

In a concentrated winding, each phase of a coil is concentrated in a single slot. The individual coil voltages induced are in phase with each other. These voltages must be added arithmetically. In order to determine the induced voltage per phase, a given coil voltage is multiplied by the number of series connected coils per phase. In actual practice, in each phase, coils are not concentrated in a single slot. They are distributed in a number of slots in space to form a polar group under each pole.

The voltages induced in coil sides are not in phase, but they differ by an angle β which is known as the angular displacement of the slots. The phasor sum of the individual coil voltages is equal to the total voltage induced in any phase of the coil.

Let,

M = slots per pole per phase

$$m = \frac{\text{slots}}{\text{poles x phases}}$$

β = angular displacement between adjacent slots in electrical degrees

$$\beta = \frac{180^\circ}{\text{slots/pole}} = \frac{180^\circ \text{ x poles}}{\text{slots}}$$

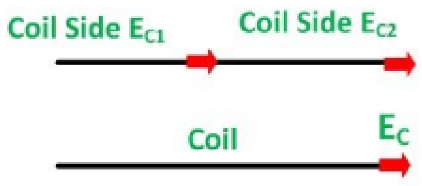
$$K_d = \frac{\text{Sin } m\,\beta/2}{m \text{ Sin } \beta/2}$$

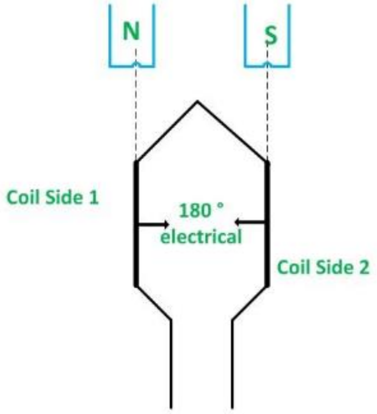
The distribution factor K_d for a given number of phases is dependent only on the number of distributed slots under a given pole. It is independent of the type of the winding, lap or wave or the number of turns per coil, etc. the distribution factor decreases as the number of slots per pole increases.

COIL SPAN FACTOR

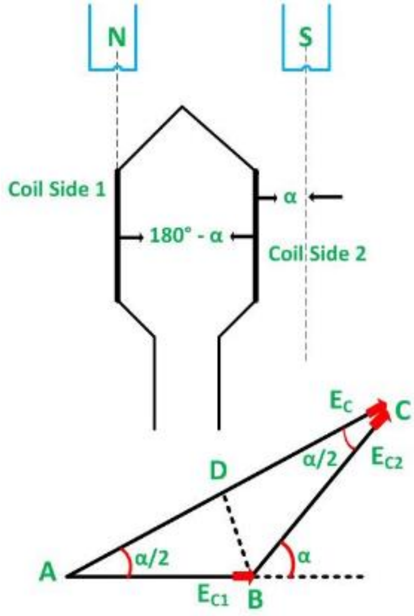
The **Coil Span Factor** or **Pitch Factor** K_C is defined as the ratio of the voltage generated in the short pitch coil to the voltage generated in the full pitch coil. The distance between he two sides of a coil is called the **Coil Span** or **Coil Pitch Factor**. It is also known as **Chording Factor.**

The angular distance between the central lines of one pole to the central line of the next pole is called **Pole Pitch**. A pole pitch is always 180 electrical degrees, regardless of the number of poles on the machine. A coil having a span equal to 180^0 electrical is called a **full pitch coil** as shown in the figure below.





A Coil having a span less than 180^0 electrical is called a **short pitch coil** or fractional pitch coil. It is also called a Chorded coil. The short pitch coil factor is shown in the figure below.



A stator winding using fractional pitch coil is called a chorded winding. If the span of the coil is reduced by an angle α electrical degrees, the coil span will be (180 – α) electrical degrees.

In case of a full pitch coil, the distance between the two sides of the coil is exactly equal to the pole pitch of 180^0 electrical. As a result, the voltage in a full pitch coil is such that the voltage of each side of the coil is in phase.

Let E_{C1} and E_{C2} be the voltages generated in the coil sides, and E_C is the resultant coil voltage.

Then the equation is given as shown below.

$$E_C = E_{C1} + E_{C2}$$

$$|E_{C1}| = |E_{C2}| = E_1 \quad (\text{Say})$$

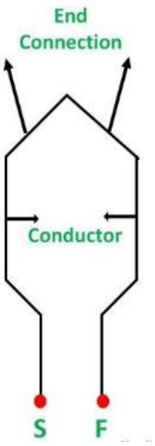
Since E_{C1} and E_{C2} are in phase, the resultant coil voltage E_C is equal to their arithmetic sum.

ARMATURE WINDING:

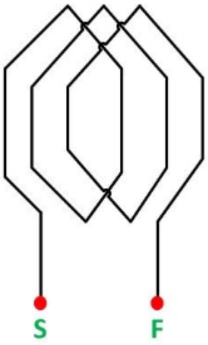
Armature Winding is the windings, in which voltage is induced. The **Field Winding** is the winding in which the main field flux is produced when the current through the winding is passed. Some of the **basic terms** related to the Armature Winding are defined as follows:

- **Turn**: A turn consists of two conductors connected to one end by an end connector.
- **Coil**: A coil is formed by connecting several turns in the series.
- **Winding**: A winding is formed by connecting several coils in series.

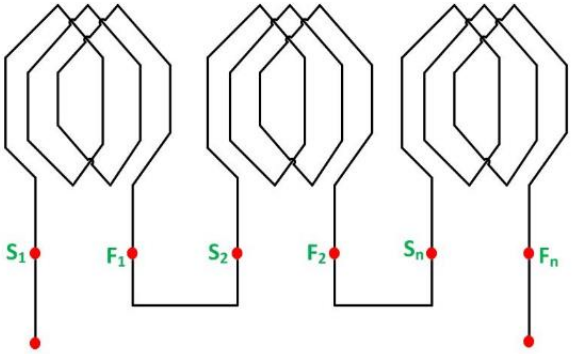
The figure of the **turn** is shown below.



The figure of the **coil** is shown below.



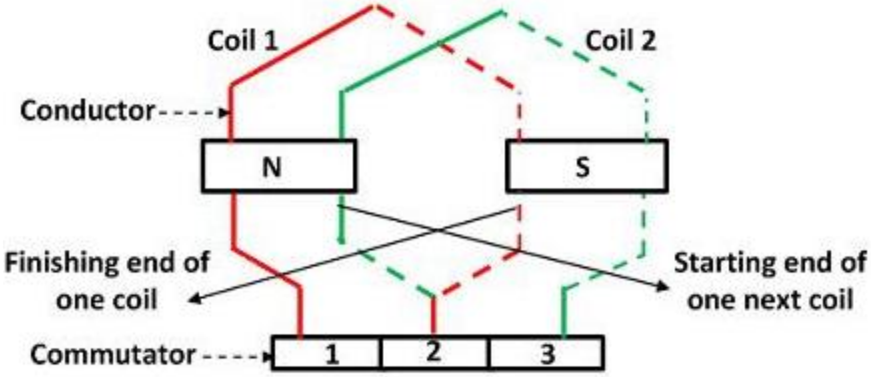
The figure of the **winding** is shown below.



The beginning of the turn or coil is identified by the symbol **(S)** meaning **Start**, and the end of the turn or coil is represented by the symbol **(F)** meaning **Finish**.

LAP WINDING

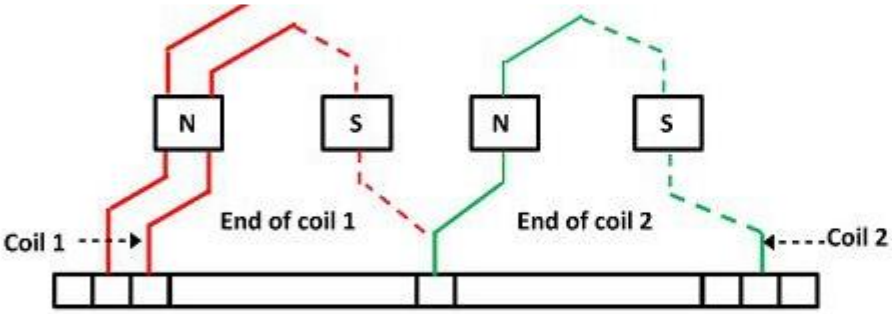
In lap winding, the consecutive coils overlap each other. The first end of the winding is connected to the one segment of the commutator, and the starting end of the other coil is placed under the same magnet (different pole) and join with the same segment of the commutator.



The conductors are connected in such a way that the number of parallel paths equals to the number of poles. Consider the machine has P poles and Z armature conductors, then there will be P parallel paths, and each path will have Z/P conductors in series.

WAVE WINDING

The one end of the coil is connected to the starting end of the other coil which has the same polarity as that of the first coil. The coils are connected in the wave shape and hence it is called the wave winding. The conductor of the wave winding are split into two parallel paths, and each path had Z/2 conductors in series. The number of brushes is equal to 2, i.e., the number of parallel paths.



Basis For Comparison	Lap Winding	Wave Winding
Definition	The coil is lap back to the succeeding coil.	The coil of the winding form the wave shape.
Connection	The end of the armature coil is connected to an adjacent segment on the commutators.	The end of the armature coil is connected to commutator segments some distance apart.
Parallel Path	The numbers of parallel path are equal to the total of number poles.	The number of parallel paths is equal to two.
Other Name	Parallel Winding or Mulitiple Winding	Two-circuit or Series Winding.
EMF	Less	More
Number of Brushes	Equal to the number of parallel paths.	Two
Types	Simplex and Duplex lap winding.	Progressive and Retrogressive wave winding
Efficiency	Less	High
Additional Coil	Equalizer Ring	Dummy coil
Winding Cost	High (because more conductor is required)	Low
Uses	In low voltage, high current machines.	In high voltage, low current machines.

V CURVE OF A SYNCHRONOUS MOTOR:

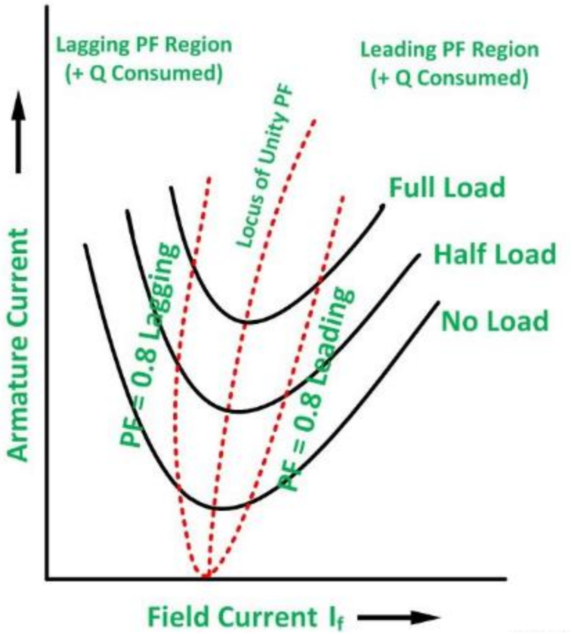
V curve is a plot of the stator current versus field current for different constant loads. The Graph plotted between the **armatures current (I_a)**and **field current (I_f)**at no load the curve is obtained known as **V Curve**.

Since the shape of these curves is similar to the letter **V**, thus they are called **V curve of synchronous motor.**

The power factor of the synchronous motor can be controlled by varying the field current I_f. As we know that the armature current I_a changes with the change in the field current I_f. Let us assume that the motor is running at NO load. If the field current is increased from this small value, the armature current I_a decreases until the armature current becomes minimum. At this minimum point, the motor is operating at unity power factor. The motor operates at lagging power factor until it reaches up to this point of operation.

If now, the field current is increased further, the armature current increases and the motor start operating as a leading power factor. The graph drawn between armature current and field current is known as V curve. If this procedure is repeated for various increased loads, a family of curves is obtained.

The **V curves** of a synchronous motor are shown below.

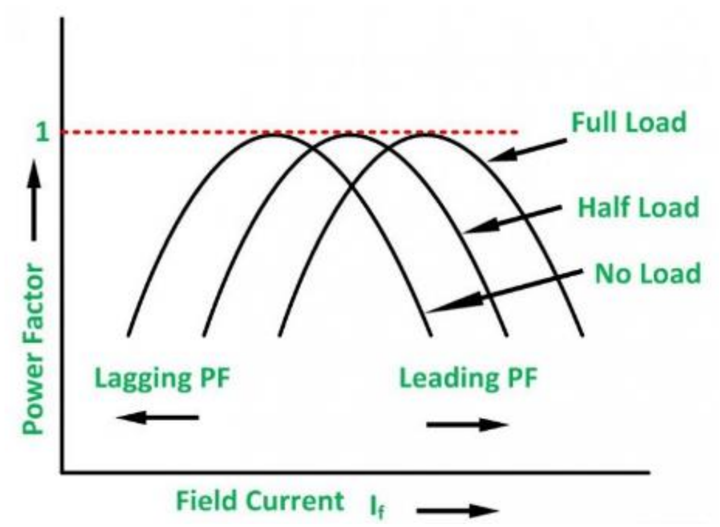


The point at which the unity power factor occurs is at the point where the armature current is minimum. The curve connecting the lowest points of all the V curves for various power levels is called the **Unity Power Factor Compounding Curve**. The compounding curves for 0.8 power factor lagging and 0.8 power factor leading are shown in the figure above by a red dotted line.

The loci of constant power factor points on the V curves are called **Compounding Curves**. It shows the manner in which the field current should be varied in order to maintain constant power factor under changing load. Points on the right and left of the unity power factor corresponds to the over excitation and leading current and under excitation and lagging current respectively.

The V curves are useful in adjusting the field current. Increasing the field current If beyond the level for minimum armature current results in leading power factor. Similarly decreasing the field current below the minimum armature current result results in lagging power factor. It is seen that the field current for unity power factor at full load is more than the field current for unity power factor at no load.

The figure below shows the graph between power factor and field current at the different loads.



It is clear from the above figure that, if the synchronous motor at full load is operating at unity power factor, then removal of the shaft load causes the motor to operate at a leading power factor.

ARMATURE REACTION IN A SYNCHRONOUS MACHINE

The effect of Armature (stator) flux on the flux produced by the rotor field poles is called **Armature Reaction**. When the current flows through the armature winding of the an alternator, a flux is produced by the resulting MMF. This armature flux reacts with the main pole flux, causing the resultant flux to become either less than or more than the original main field flux.

Pull-out torque is defined as the maximum value of the torque which a synchronous motor can develop at rated voltage and frequency without losing synchronism. It values varies from **1.5** to **3.5** times the full load torque.

VOLTAGE REGULATION OF A SYNCHRONOUS GENERATOR

The **Voltage Regulation** of a **Synchronous Generator** is the rise in voltage at the terminals when the load is reduced from full load rated value to zero, speed and field current remaining constant. It depends upon the power factor of the load. For unity and lagging power factors, there is always a voltage drop with the increase of load, but for a certain leading power, the full load voltage regulation is zero.

The voltage regulation is given by the equation shown below.

$$\text{Per Unit Voltage Regulation} \triangleq \frac{|E_a| - |V|}{|V|} \dots\dots\dots(1)$$

$$\text{Percentage Voltage Regulation} \triangleq \frac{|E_a| - |V|}{|V|} \dots\dots\dots(2)$$

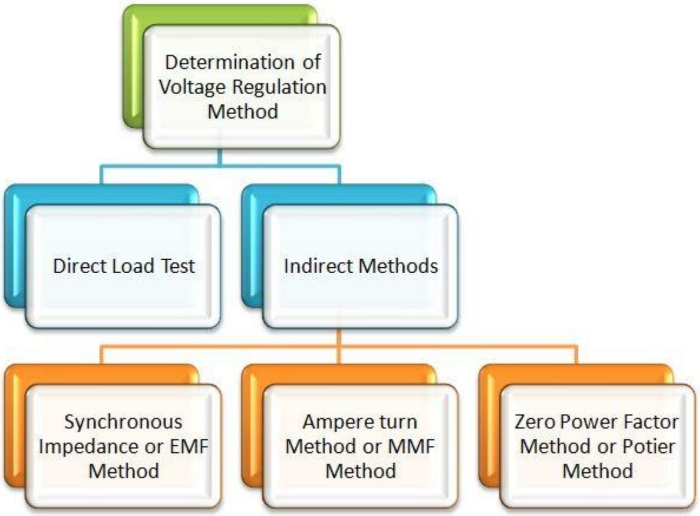
Where,

- **$|E_a|$** is the magnitude of a generated voltage per phase
- **$|V|$** is the magnitude of rated terminal voltage per phase

In this case, the terminal voltage is the same for both full load and no load conditions. At lower leading power factors, the voltage rises with the increase of load, and the regulation is negative.

DETERMINATION OF VOLTAGE REGULATION

There are mainly two methods which are used to determine the regulation of voltage of a smooth cylindrical rotor type alternators. They are named as **direct load test** method and **indirect methods** of voltage regulation. The indirect method is further classified as **Synchronous Impedance** Method, **Ampere-turn** Method and **Zero Power Factor** Method.



DIRECT LOAD TEST:

The alternator runs at synchronous speed, and its terminal voltage is adjusted to its rated value V. The load is varied until the Ammeter and Wattmeter indicate the rated values at the given power factor. The load is removed, and the speed and the field excitation are kept constant. The value of the open circuit and no load voltage is recorded.

It is also found from the percentage voltage regulation and is given by the equation shown below.

$$\% \text{ Voltage Regulation} = \frac{E_a - V}{V} \text{ x } 100\%$$

The method of direct loading is suitable only for small alternators of the power rating less than 5 kVA.

INDIRECT METHODS OF VOLTAGE REGULATION:

For large alternators, the three indirect methods are used to determine the voltage regulation they are as follows.

- Synchronous Impedance Method or EMF method.
- Ampere-turn method or MMF method of Voltage Regulation.
- Zero Power Factor method or Potier Method

SYNCHRONOUS IMPEDANCE METHOD

The **Synchronous Impedance Method or Emf Method** is based on the concept of replacing the effect of armature reaction by an imaginary reactance. For calculating the regulation, the synchronous method requires the following data; they are the armature resistance per phase and the open circuit characteristic.The open circuit characteristic is the graph of the circuit voltage and the field current. This method also requires short circuit characteristic which is the graph of the short circuit and the field current.

or a synchronous generator following are the equation given below

$$V = E_a - Z_s I_a$$

Where,

$$Z_s = R_a + jX_s$$

For calculating the synchronous impedance, Z_s is measured, and then the value of E_a is calculated. From the values of E_a and V, the voltage regulation is calculated.

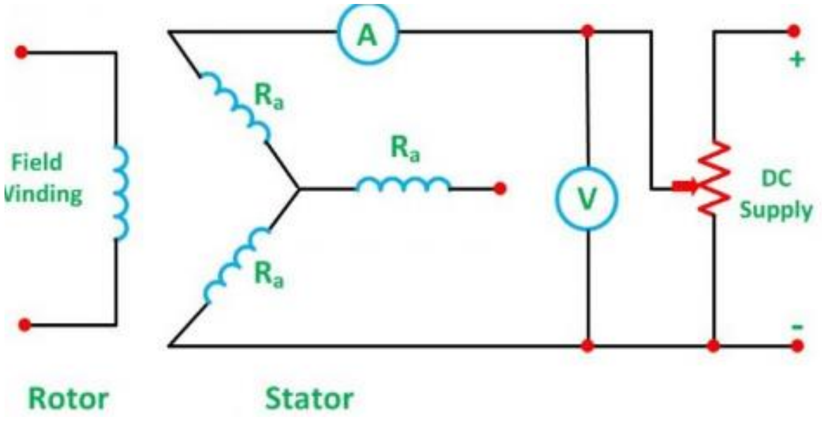
MEASUREMENT OF SYNCHRONOUS IMPEDANCE

The measurement of synchronous impedance is done by the following methods. They are known as

- DC resistance test
- Open circuit test
- Short circuit test

DC RESISTANCE TEST:

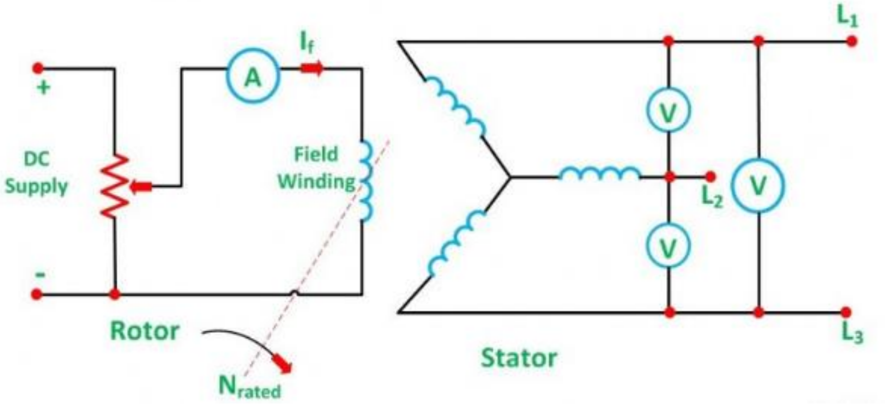
In this test, it is assumed that the alternator is star connected with the DC field winding open as shown in the circuit diagram below.



It measures the DC resistance between each pair of terminals either by using an ammeter – voltmeter method or by using the Wheatstone's bridge. The average of three sets of resistance value R_t is taken. The value of R_t is divided by 2 to obtain a value of DC resistance per phase. Since the effective AC resistance is larger than the DC resistance due to skin effect. Therefore, the effective AC resistance per phase is obtained by multiplying the DC resistance by a factor 1.20 to 1.75 depending on the size of the machine. A typical value to use in the calculation would be 1.25.

OPEN CIRCUIT TEST

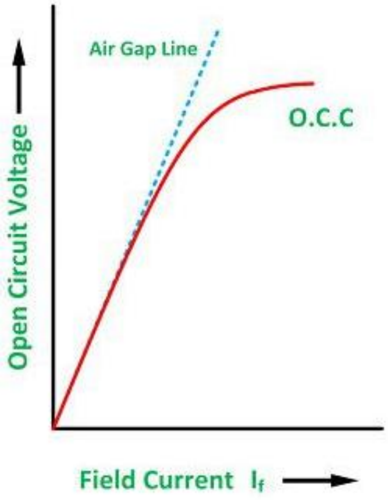
In the **open circuit test** for determining the synchronous impedance, the alternator is running at the rated synchronous speed, and the load terminals are kept open. This means that the loads are disconnected, and the field current is set to zero. The circuit diagram is shown below.



After setting the field current to zero, the field current is gradually increased step by step. The terminal voltage E_t is measured at each step. The excitation current may be increased to get 25% more than the rated voltage. A graph is drawn between the open circuit phase voltage $E_p = E_t/\sqrt{3}$ and the field current I_f. The curve so obtains called Open Circuit

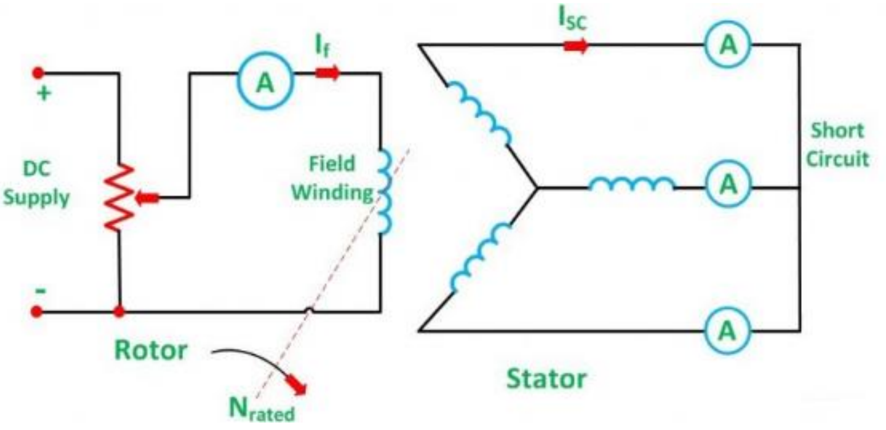
Characteristic (O.C.C). The shape is same as normal magnetisation curve. The linear portion of the O.C.C is extended to form an air gap line.

The **Open Circuit Characteristic (O.C.C)** and the air gap line is shown in the figure below.



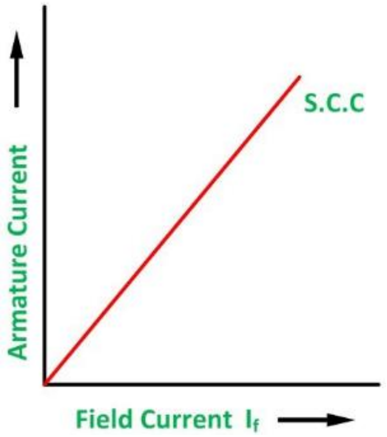
SHORT CIRCUIT TEST

In the **short circuit test**, the armature terminals are shorted through three ammeters as shown in the figure below.



The field current should first be decreased to zero before starting the alternator. Each ammeter should have a range greater than the rated full load value. The alternator is then run at synchronous speed. Same as in an open circuit test that the field current is increased gradually in steps and the armature current is measured at each step. The field current is increased to get armature currents up to 150% of the rated value.

The value of field current If and the average of three ammeter readings at each step is taken. A graph is plotted between the armature current Ia and the field current If. The characteristic so obtained is called **Short Circuit Characteristic (S.C.C)**. This characteristic is a straight line as shown in the figure below.



EXCITATION SYSTEM OF A SYNCHRONOUS MACHINE

The word **Excitation** means the production of flux by passing current in the field winding.The arrangement or the system used for the excitation of the synchronous machine is known as **Excitation System**. To excite the field winding of the rotor of the synchronous machine, direct current is required. Direct current is supplied to the rotor field of the small machine by a DC generator called **Exciter**. A small DC generator called **Pilot Generator**, supplies the current to the Exciter.

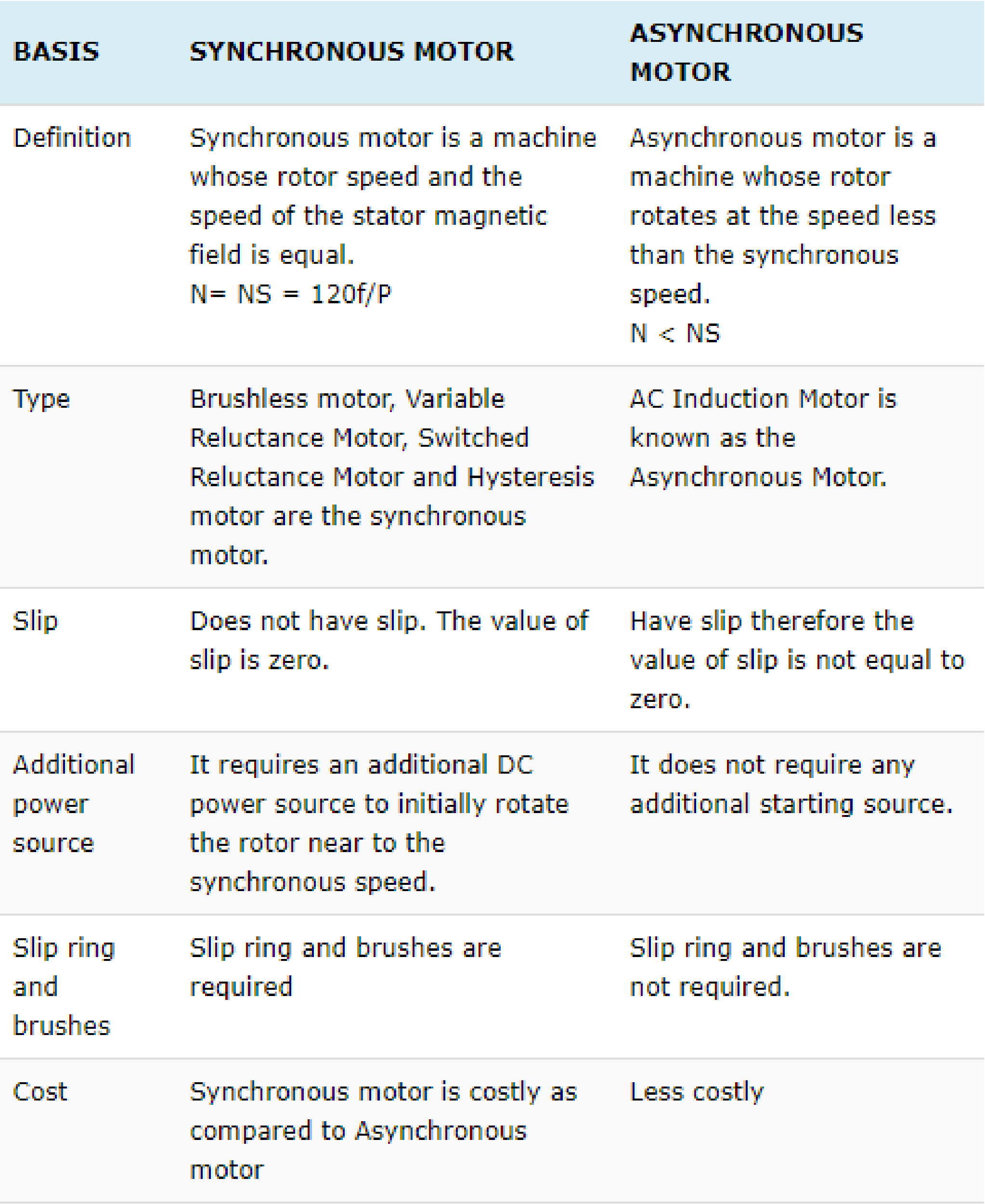
The Exciter and the Pilot Exciter both are mounted on the main shaft of the Synchronous generator or motor. The DC output of the main Exciter is given to the field winding of the synchronous machine through brushes and slip rings. The pilot exciter is excluded in smaller machines.

For medium size machines, **AC Exciters** are used in place of DC Exciter. AC Exciters are three phase AC generators. The output of an AC Exciter is rectified and supplied through the brushes, and the slip rings to the rotor winding of the synchronous machine.

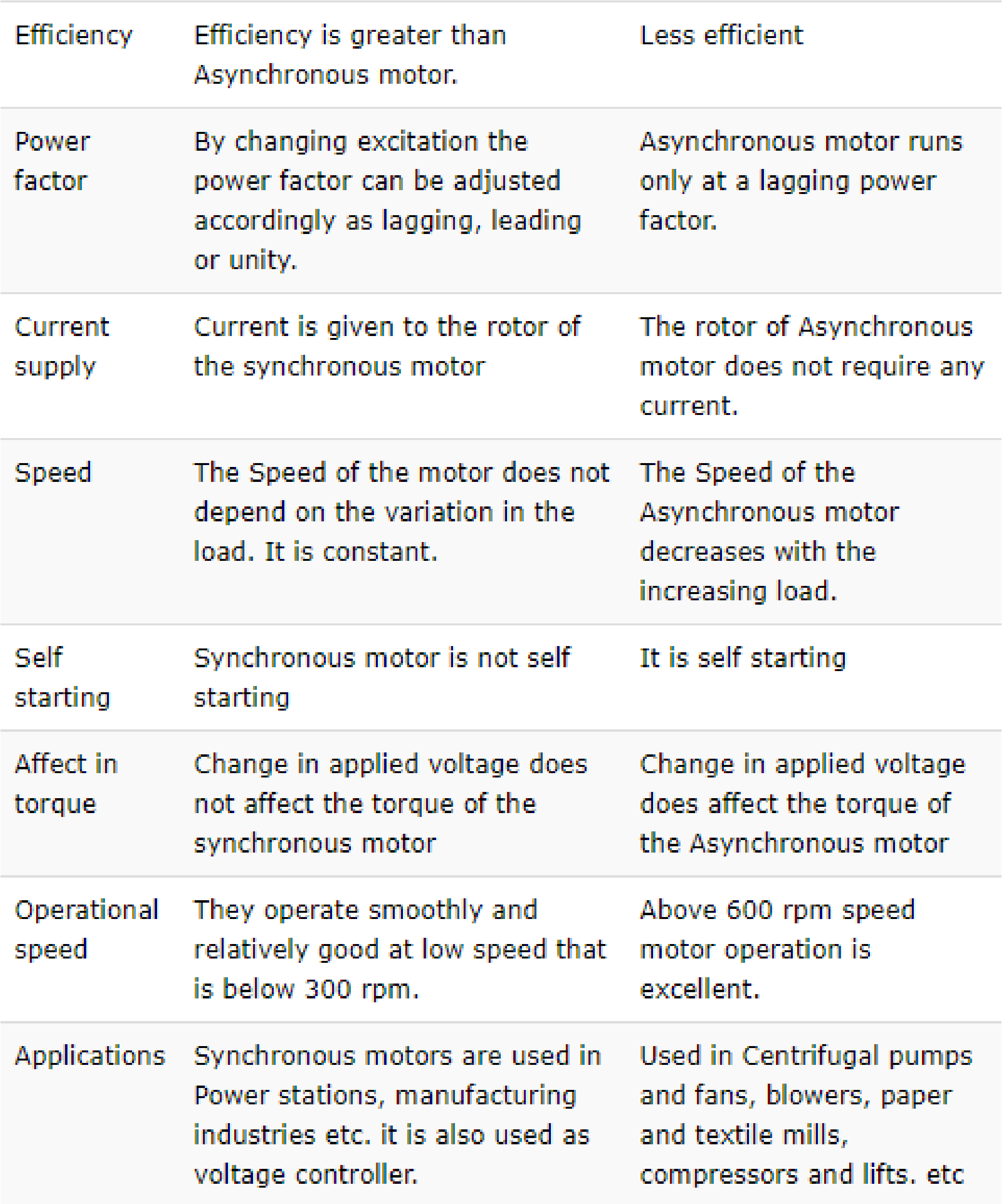
For large synchronous generators having few hundred megawatt ratings, the Excitation System requirement becomes very large. The problem of conveying such a large amount of power through the high-speed sliding contacts becomes formidable.

Presently, the large synchronous machines are using **Brushless Excitation System**. A Brushless Exciter is a small direct coupled AC generator with its field circuit on the stator and the armature circuit on the rotor. The three phase output of the AC exciter generator is rectified by solid state rectifiers. The rectified output is connected directly to the field winding, thus eliminating the use of brushes and slip rings.

A Brushless excitation system requires less maintenance due to the absence of brushes and slip rings. The power loss is also reduced. The DC required for the field of the exciter itself is sometimes provided by a small pilot exciter. A pilot exciter is a small AC generator with a permanent magnet mounted on the rotor shaft and the three phase winding on the stator. It provides the field current of the exciter. The exciter supplies the field current of the main machine. Thus, the use of a pilot exciter makes the excitation of the main generator completely independent of external supplies.



BASIS	SYNCHRONOUS MOTOR	ASYNCHRONOUS MOTOR
Definition	Synchronous motor is a machine whose rotor speed and the speed of the stator magnetic field is equal. N= NS = 120f/P	Asynchronous motor is a machine whose rotor rotates at the speed less than the synchronous speed. N < NS
Type	Brushless motor, Variable Reluctance Motor, Switched Reluctance Motor and Hysteresis motor are the synchronous motor.	AC Induction Motor is known as the Asynchronous Motor.
Slip	Does not have slip. The value of slip is zero.	Have slip therefore the value of slip is not equal to zero.
Additional power source	It requires an additional DC power source to initially rotate the rotor near to the synchronous speed.	It does not require any additional starting source.
Slip ring and brushes	Slip ring and brushes are required	Slip ring and brushes are not required.
Cost	Synchronous motor is costly as compared to Asynchronous motor	Less costly



Efficiency	Efficiency is greater than Asynchronous motor.	Less efficient
Power factor	By changing excitation the power factor can be adjusted accordingly as lagging, leading or unity.	Asynchronous motor runs only at a lagging power factor.
Current supply	Current is given to the rotor of the synchronous motor	The rotor of Asynchronous motor does not require any current.
Speed	The Speed of the motor does not depend on the variation in the load. It is constant.	The Speed of the Asynchronous motor decreases with the increasing load.
Self starting	Synchronous motor is not self starting	It is self starting
Affect in torque	Change in applied voltage does not affect the torque of the synchronous motor	Change in applied voltage does affect the torque of the Asynchronous motor
Operational speed	They operate smoothly and relatively good at low speed that is below 300 rpm.	Above 600 rpm speed motor operation is excellent.
Applications	Synchronous motors are used in Power stations, manufacturing industries etc. it is also used as voltage controller.	Used in Centrifugal pumps and fans, blowers, paper and textile mills, compressors and lifts. etc

HUNTING IN A SYNCHRONOUS MOTOR

The phenomenon of oscillation of the rotor about its final equilibrium position is called **Hunting.** On the sudden application of load, the rotor search for its new equilibrium position and this process is known as **Hunting**. The Hunting process occurs in a synchronous motor as well as in synchronous generators if an abrupt change in load occurs.

CAUSES OF HUNTING

The various causes of hunting are as follows:-

- Sudden changes of load.
- Faults were occurring in the system which the generator supplies.

- Sudden change in the field current.
- Cyclic variations of the load torque.

EFFECT OF HUNTING

The various effects of hunting are as follows:-

- It can lead to loss of synchronism.
- It can cause variations of the supply voltage producing undesirable lamp flicker.
- The possibility of Resonance condition increases. If the frequency of the torque component becomes equal to that of the transient oscillations of the synchronous machine, resonance may take place.
- Large mechanical stresses may develop in the rotor shaft.
- The machine losses increases and the temperature of the machine rises.

REDUCTION OF HUNTING

The following technique given below is used to reduce the phenomenon of hunting.

- **Use of damper windings**
- **Uses of flywheels**

The prime mover is provided with a large and heavy flywheel. This increases the inertia of the prime mover and helps in maintaining the rotor speed constant.

CHAPTER-4

SPECIAL PURPOSE MACHINES

The machines which are designed specially to perform a particular job are called **special purpose machines**.

SERVOMOTOR:

The motors which respond to the error signal abruptly and accelerate the load quickly are called **servomotors.**

Types of Servomotors:

1. DC Servomotors
2. AC Servomotors.

- DC Servomotors are preferred because of their high torque to inertia ratio and high starting torque.
- AC servomotors are known for their reliability and freedom from commutation problems such as noise and wearing of brushes etc.

SCHRAGE MOTOR:

The demand of the industry to have a motor of moderate size having desirable features of speed control and power factor improvement without the auxiliary devices was met with when **K H Schrage** of Sweden developed such a motor and was named as Schrage motor.

Schrage motor is a motor that contains both power factor correction arrangement and speed control in one and the same motor.

This motor is also known as **Brush shift AC motor**.

This motor provides characteristics **similar to a DC shunt motor**, hence it is also **called as AC shunt motor.**

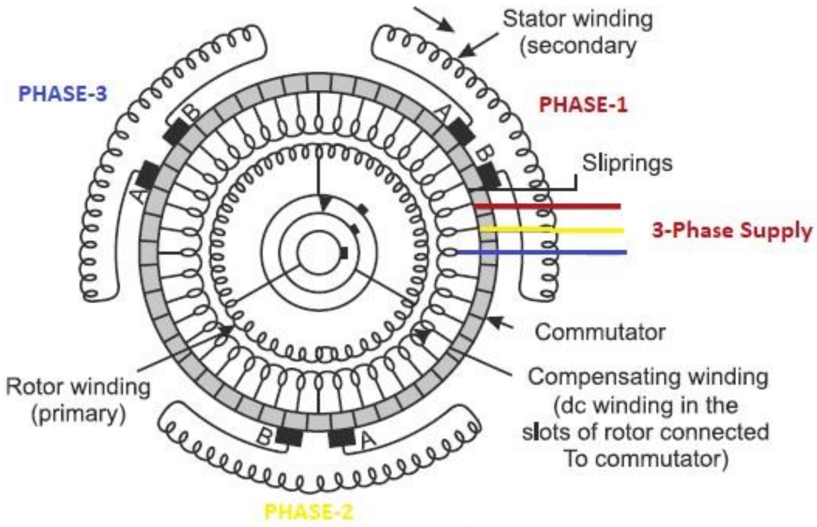


FIG: SCHARGE MOTOR

ADVANTAGE:

1. It has a continuous speed regulation with the required range so that the driven machinery may be run at the best possible speeds.
2. It has high average efficiency and power factor.

APPLICATIONS:

There are many industrial applications of the Schrage motor are:

1. It is used in printing industry in which variable speed is essential.
2. It is used in paper industry.
3. In rubber industry this motor is extensively employed.
4. In Steam boiler installations, Schrage motor are commonly employed for boiler fans and strokes drives.
5. In cement kilns
6. Cranes
7. Lifting pumps
8. Large machine tools
9. Sugar refining machinery
10. In textile industry
11. In belt conveyors

BRUSHLESS MOTOR:

A conventional DC motors require more maintenance and need to replace brushes periodically and their operating voltage and speed is limited because of commutation difficulties.

To over-come these difficulties, we have to eliminate commentator and brushes.

Thus, a motor that retains the characteristics of a DC motor but eliminates the commutator and brushes is called a **brushless DC motor.**

The brushless DC motors are equipped with electronic circuits and devices which perform the same function as that of a mechanical commutator.

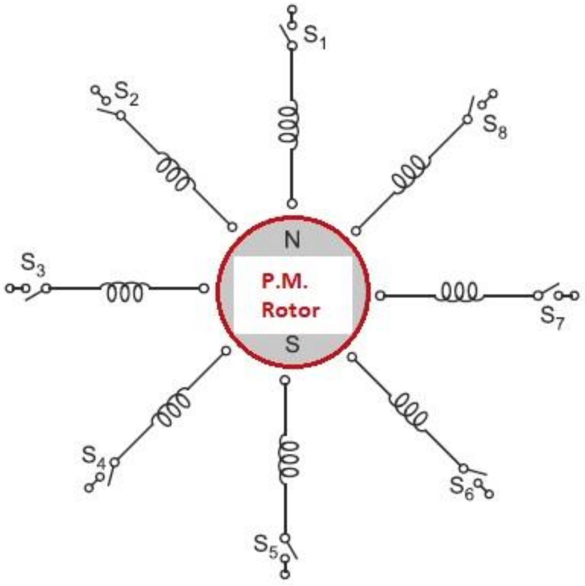


FIG: DIAGRAM OF BRUSHLESS DC MOTOR

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ADVANTAGES:

1. Losses are less.
2. More operating efficiency.
3. Require little or no maintenance.
4. Have longer operating life.
5. No sparking.
6. No combustible fluids and gases.
7. Very reliable and efficient.
8. Capable to run at very high speeds (more than 40000 rpm).

DISADVANTAGES:

1. More expressive then conventional DC motors.
2. Additional electronic circuit and devises are required that increases the overall size of the machine.

APPLICATION:

It applications are:

1. In aerospace industry
2. In Satellites, gyroscope and high efficiency robotic system.
3. In artificial heart pumps.
4. In disc drives.
5. In video recorders.
6. In biomedical fields.

LINEAR INDUCTION MOTOR (LIM):

A conventional induction motor gives a circular motion whereas, a linear induction motor gives a linear or translational motion.

Thus, a **linear induction motor (LIM)** is a motor which gives a linear or translational motion instead of rotational motion as is obtained from a conventional induction motor.

CONSTRUCTION:

To understand its construction, consider a 3-phase conventional induction motor as shown in Fig. (a). Cut it along the axis A A’ and spread out flat as shown in Fig.(b).

The stator winding is placed in the stator core called **primary**, whereas, the rotor short circuited ring is called **secondary**.

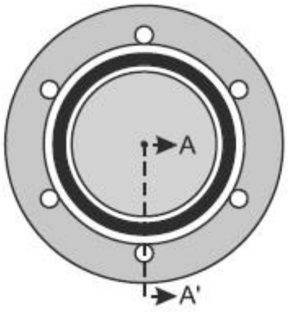
In the linear induction motors the secondary consists of a flat aluminium conductor with ferromagnetic core.

WORKING:

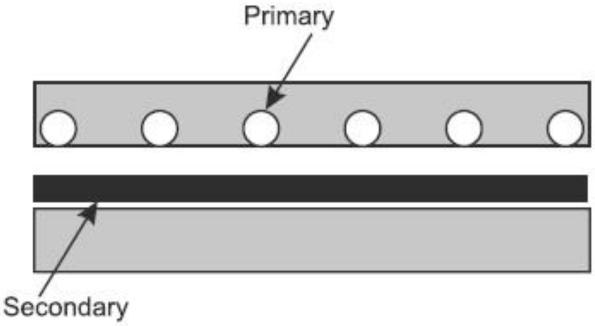
As in case of conventional 3-phase induction motor, when 3-phase supply is given to the stator, a resulting rotating flux is produced. Similarly, in case of linear 3-phase induction motor when 3-phase supply is given to its primary, a resultant travelling flux is produced which travels from one end to the other and repeats the same. EMF or current is induced in the aluminium conductor due to relative motion between the travelling primary field and stationary aluminium conductor or strip.

BY the interaction of field produced by the secondary and the primary a linear force (or thrust) **F** is produced. If the secondary is kept fixed and primary is allowed to move, the force or thrust will move the primary in the direction of travelling field.

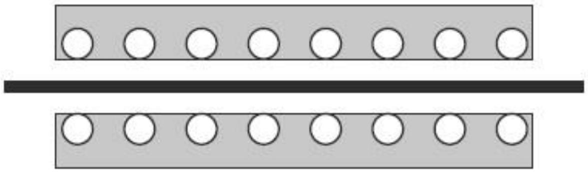
The linear induction motor (LIM) shown in Fig. (b) is called a **single-sided linear induction motor (*SLIM*).** However, the primary can be placed on both the sides of the secondary, as shown in Fig.(c). Then the motor is called **double-sided linear induction motor (*DLIM*)**



(a) Conventional
Induction Motor's Structure



(b) Single-Slided linear
Induction motor



(c) Double-Slided LIM

APPLICATIONS:

1. In transportation where primary is mounted on the vehicle and secondary is laid along the track.
2. In cranes for material handily pumping of liquid metals.
3. In actuators for door movements.
4. In actuators for high voltage circuit breakers.